SONAR DETECTION AND CLASSIFICATION OF BURIED OR PARTIALLY BURIED OBJECTS IN CLUTTERED ENVIRONMENTS

Steven G. Schock
Lester R. LeBlanc
Department of Ocean Engineering
Florida Atlantic University
Boca Raton, Fl. 33431-0991
Phone: 407-367-3442(Schock); 407-367-2792(LeBlanc)
Fax: 407-367-3885
Email: schock@oe.fau.edu; leblanc@oe.fau.edu
Award #:N00014-96-1-5027

LONG-TERM GOALS

1. Develop acoustic imaging technology that will allow UUVs to find and classify objects buried under the seabed
2. Improve acoustic remote sensing technologies that will allow UUVs to measure acoustic and physical seabed properties

OBJECTIVES

1. Develop a sonar model to predict the performance of a sonar using an adaptive nearfield beamformer for detecting and imaging buried objects of various sizes and aspects in all sediment types.
2. Develop a database of buried target strengths and sediment volume scattering strengths that are required for the sonar model
3. Develop signal processing procedures for automatically extracting and storing images of buried objects
4. Develop a prototype sonar for generating real time images of buried objects and testing signal processing procedures
5. Investigate using boundary waves for detecting buried objects beyond the critical angle
6. Develop a low power compact sonar for installation in UUVs

APPROACH

In order to detect and locate objects buried under the seabed, a sonar must have a narrow beamwidth and wide bandwidth to reduce volume scattering below the level of the target echo. A additional requirement is that the sonar must operate below 10 kHz to reduce absorption in sand. The low operating band requires that receiving array aperture be a least 2 meters in size and have at least 16 channels to provide sufficient spatial filtering for scattering noise. Due to the high volume scattering strengths of sands and the relatively low target strengths of buried objects of interest, the sonar must be towed within 5 meters of the seabed. Therefore, the targets will be in the nearfield of the sonar thereby resulting in substantial differences in target - receiver path length (much greater than a 1/4 wavelength) from one array segment to another. Near field focusing requires that the path length (or

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1997**	2. REPORT TYPE	3. DATES COVERED **00-00-1997 to 00-00-1997**
4. TITLE AND SUBTITLE **Sonar Detection and Classification of Buried or Partially Buried Objects in Cluttered Environments**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Florida Atlantic University,Department of Ocean Engineering,777 Glades Road,Boca Raton,FL,33431**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

time delay) from the target to each array be known within a 1/8 of a wavelength for accurate focusing. Coherently summing the reflections measured by the receiving arrays due to a single target is required to achieve the optimum signal to scattering noise ratio. The arrival times of the echoes from a target depend on the sound speeds of the sediment and water, the path of the refracted signal, the pitch and roll of the vehicle, and vehicle height. Coherent addition of the 16 target reflections also requires that corrections be made for attenuation, the beam pattern function of the sonar transmitting and receiving arrays and the transmission coefficients through the sediment water interface which will be different for transmitter-target and receiver-target paths because the sonar is bistatic.

To achieve the sonar performance described above, a 16 channel towed sonar was developed to test signal processing and image processing techniques for detecting and classifying buried objects. The sonar transmits at a rate of 20 pulses per seconds to ensure that an across track slice of the seabed is generated at least every 10 cm along track.

As mentioned in the foregoing paragraph, the range of volume scattering strengths and buried targets strengths must be known to determine sonar performance and sonar designs for buried object imaging. Consequently the first step of this project is to develop a database of volume scattering strengths and buried target strengths. Until this project there has been no significant work done on measuring volume scattering strengths and buried target strengths. A 16 channel quantitative sonar was developed for measuring buried target strengths and volume scattering strengths as well as for collecting data used in the developing 2D and 3D imaging and classification algorithms. This sonar is designed to measure target strengths with an accuracy of better than 1 dB. The two way transmission loss, used in the target strength calculations, is estimated using sound speed and attenuation measurements directly estimated from the reflection data. The two way transmission loss and the measured aperture function of the transmitting and receiving arrays are used to measure volume scattering strengths as a function of depth under the seabed.

The output of the beamformer is a vertical slice of the seabed. A vertical slice is generated immediately after each transmission. The pixel data in the 2D slice is placed in a 3D matrix at positions
that account for along track translation between transmissions and vehicle pitch and roll. Targets are detected by searching for searching for edges and increased regions of energy in the data set. The analysis of images will determine the target echo strength to scattering noise ratio that is required for automatic target logging and identification. Automatic target detection is critical for the buried object imaging application be 2D slices are being generated every 50 msec so the data rates are too high for real time visualization using the slices. The 3D data matrix of image pixels must be searched for targets and then each target must be displayed for the operator showing different slices of the target. Once a sonar model is developed for predicting buried object detection and classification and a database of volume scattering strengths and buried target strengths is collected, a sonar can be designed for UUV operations.

Jim Wulf, an electrical engineer, supervised the repackaging of vehicle electronics into underwater canisters. Matt Singer programmed the DSP processor and programmed the sonar data control software running under Windows 95. Arnaud Tellier, a graduate student, is investigating the simulation of sonar imagery for various targets and methods of detecting the targets and extracting the targets from a 3D image matrix.

WORK COMPLETED

1. The data acquisition and signal processing electronics for the buried object sonar system were packaged in an 8 inch ID underwater canister. The power requirement for the transceiver and processing cards was reduced to 250 Watts to support the UUV application. A 6 slot PCI backplane

was developed since none were commercially available. The sonar processing computer was changed from a VME based system to a PCI based system to take of advantage of availability of relatively inexpensive PCI processing cards. A 1200 Watt class D amplifier for the transceiver was developed to reduce the heat sources to allow packaging in the tube and to reduce the power requirements. A 100 Mbps ethernet telemetry system was developed for transferring the data to a topside processor when the sonar vehicle is used in a towed mode; it has been tested up to cable lengths of 1000 ft.

2. Adaptive beamforming procedures to revised to reduce memory requirements for generating complex beamforming coefficients in real time. Lookup tables used to calculate beamforming coefficients were compressed by a factor of 20 to implement real time adaptive beamforming which corrects for seafloor slope, vehicle pitch, roll and height, sediment and water sound speed variations, refraction, attenuation, and boundary losses.

3. An at sea procedure was developed for checking the sonar calibration at sea. The effort was required to solve the problem of calibrating a 3 meters by 1 meter vehicle, which was too large to calibrate in the FAU test tank which is 4 meters deep. A 25 cm air-filled rubber ball was verified in tank testing to behave as a pressure release sphere which has a relatively flat frequency response over the sonar frequency range making the air-filled ball a much better target than calibrated spherical shells for wideband sonar systems.

4. Data sets were processed to estimate the target strengths of buried concrete-filled steel cylinders with diameters of 12 and 18 inches and with varying aspects over the frequency range of 1000-10000 Hz. The cylinders are covered by 1 to 1.5 meters of sand. Target strengths were 6 dB lower than expected. Refinements in system calibration and focusing algorithms are in progress.

RESULTS

The most significant result was establishing that an air-filled rubber ball can be used to calibrate the imaging sonar over a broad frequency range (1-10 kHz). Impulse response measurements of a 25 cm air-filled rubber ball show that the impulse response agrees closely with the theoretical response of a pressure release sphere. Since a pressure release sphere has well know scattered field without resonances, the air-filled rubber ball is an ideal acoustic target for calibrating the sonar at sea. Figure 1 shows the measured incident and the backscattered pressure due to a bandlimited acoustic impulse striking the air filled rubber ball. Note the echo is followed by tank wall reflections. The backscattered pressure agrees closely with the theoretical backscattered pressure for a pressure release sphere of the same diameter. Figure 2 shows the theoretical impulse response calculated using the following expression for the frequency response of a pressure release sphere of radius a .

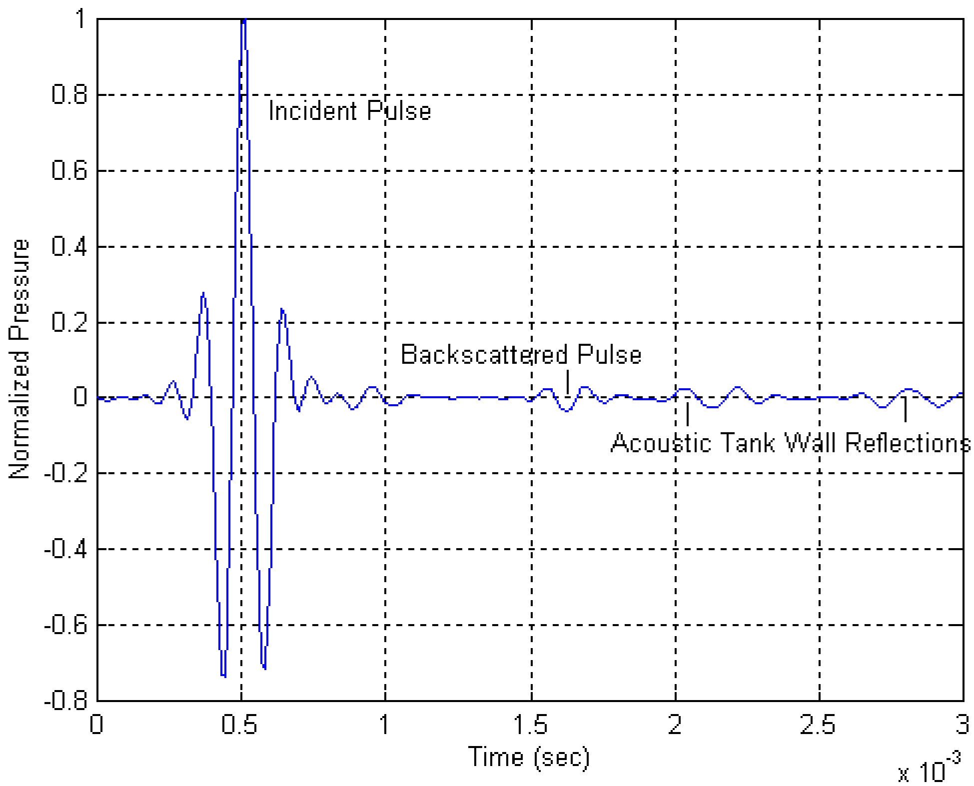
$$p(r,q) = P_0 \sum_{n=0}^{\infty} c_n h_n(kr) P_n(\cos q)$$

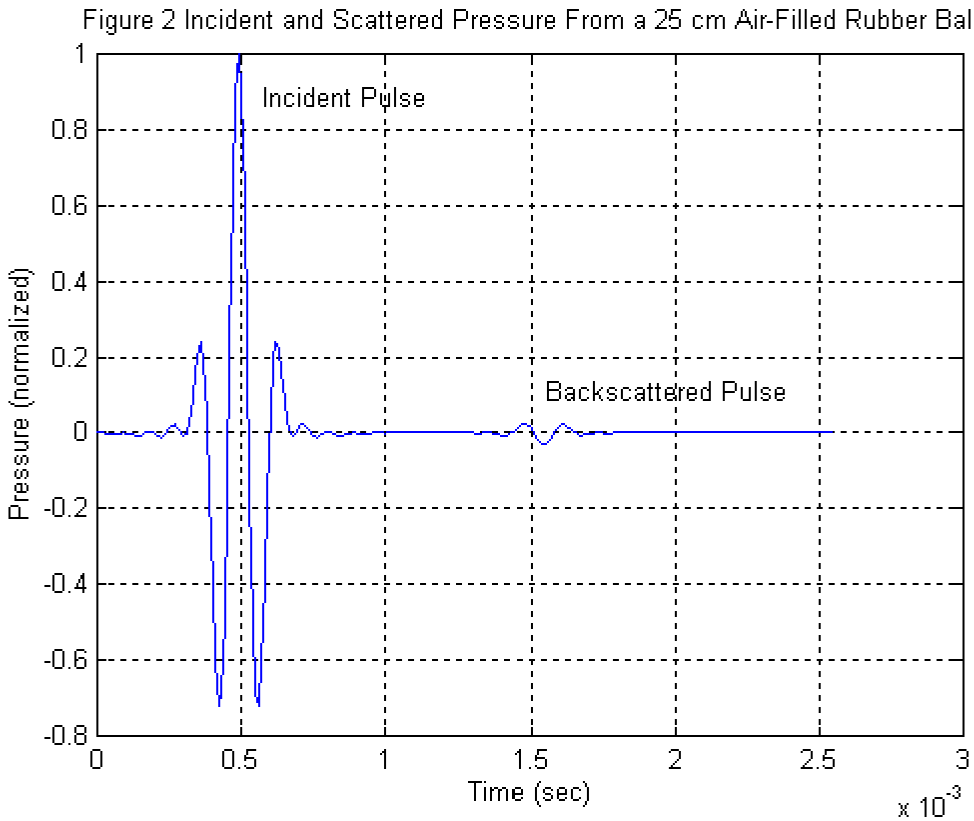
$$where \quad c_n = k(-1)^n (2n+1) h_n(kr_0) \sin \boldsymbol{h}_n e^{-jh_n}$$

$$and \quad \tan \boldsymbol{h}_n = \frac{-j_n(ka)}{n_n(ka)}$$

P_0 is the source pressure of a point source that is a distance r_0 from the center of the pressure release sphere. j_n, n_n and h_n are spherical Bessel functions and P_n is a Legendre polynomial. The field point is located at a distance r and at an angle q from the measure from the center of the sphere. For the experimental results described in Figure 1, $q = 180^o$, $r_0 =$ 1.5 m and r = .92 m. The band limited impulse has a frequency range of 1.5 to 11.3 kHz with a center frequency at 6800 Hz. The calibration target echos will allow variations in the system aperture function and frequency response to be measured each time the buried object imaging sonar is deployed by towing the sonar above the bottom moored sphere and collecting impulse response measurements with each acoustic array. Focusing and target strength algorithms will verify system performance and allow corrections if required. This procedure will provide the quality control to confirm the target strengths and volume scattering coefficients have an accuracy of 1 dB or better.

Figure 1 Incident and Scattered Pressure From a 25 cm Air-Filled Rubber Ball





IMPACT/APPLICATIONS

This project is generating a database of volume scattering and target strengths that is needed for developing buried object imaging sonars.

TRANSITIONS

This technology is being transitioned to the State of Hawaii for use in ordnance cleanup. Commencing in November 1997, CEROS (Center for Excellence in Research in Ocean Sciences-DARPA funded) is funding the commercialization of a high resolution version of the imaging sonar developed in this project for finding buried ordnance. Commercial applications including buried pipeline and cable surveying and tracking, locating buried objects such as ordnance, drums of hazardous waste, anchors, and pieces of airline wreckage or ship wrecks.

RELATED PROJECTS

Identify closely related projects and briefly describe the nature of each relationship.
This project is closely related to the core program sponsored by ONR in high resolution acoustics (program manger, Joe Kravitz), responsible for funding the underlying chirp sonar and sediment property prediction technology.

REFERENCES

"Multi Channel FM Profiler for Buried Pipeline Surveying," S. G. Schock and L.R. LeBlanc, Offshore Technology Conference Proceedings, May 1996, OTC8029, p.659-665.

Web address: http://www.oe.fau.edu/CHIRP/CHIRP.htlm